MINERALOGY AND MICROSTRUCTURES OF SHOCK-INDUCED MELT VEINS IN THE TENHAM (L6) CHONDRITE T.G. Sharp[1,2], M. Chen[3], and A. El Goresy[4], [1]Department of Geology, Arizona State University, Tempe, AZ 85287,USA, [2]Bayerisches Geoinstitut, Universität Bayreuth, 95440 Bayreuth, Germany [3]Institute of Geochemistry, Academia Sinica, Guangzou, China, [4]Max-Planck Institut für Kernphysik, D-69029 Heidelberg, Germany.

Introduction

High-pressure minerals commonly occur in melt veins in chondrites that result from shock metamorphism during impact events on chondritic parent bodies. By combining mineralogical and microstructural observations of these melt veins with information obtained from dynamic and static high pressure experiments, it is possible to gain new insights into conditions and duration of shock metamorphism [1,2]. An important key to the interpretation of the high pressure minerals in shock induced melt veins was the discovery that the matrix of these veins resulted from crystallization of a chondritic melt at high pressure [3-7,1]. Recently the assemblage of magnesiowüstite + majorite-pyrope solid solution (majorite$_{ss}$) was found in the matrix of melt veins in the Sixangkou L6 chondrite and compared with phase equilibria data [8] to estimate the pressure and temperature of crystallization during shock [1]. It is now possible to revisit shocked chondrite samples to investigate the matrix minerals to see if similar high pressure assemblages are present and if similar conditions can be inferred. The Tenham L6 chondrite was characterized using analytical TEM [4] and found to contain majorite$_{ss}$ and a poorly characterized Fe oxide. Based on SEM and electron microprobe data, melt veins in Tenham were preliminarily interpreted to contain the majorite$_{ss}$ + magnesiowüstite assemblage and therefore to represent similar crystallization conditions to those of Sixangkou [9]. Such an interpretation can be made with confidence only if the mineralogy and microstructures of the fine-grained matrix assemblage is well characterized. The goal of this study is to use analytical transmission electron microscopy (TEM) to characterize the melt-vein assemblage in the Tenham L6 chondrite to see if the mineralogy and microstructures are similar to those in Sixangkou.

Polished sections of the Tenham L6 chondrite were investigated using a standard and a field-emission SEM for high resolution back scatter electron imaging (BSE). Regions of interest were then removed and ion thinned for examination with analytical TEM.

Results

BSE images obtained with the field emission SEM clearly resolve the majorite$_{ss}$ garnets and other phases in the matrix (Fig. 1A). The garnets are equidimensional and occur up to approximately 5 µm in size. The boundaries between the garnets are filled with a high atomic-number (Z) phase, an intermediate Z phase, and a low Z phase. The high Z material corresponds to Fe metal and sulfide, whereas the low Z material is an altered silicate glass. The majorite$_{ss}$ garnets have many inclusions of the intermediate Z material and in some cases show a delicate symplectite microstructure (Fig. 1A). The Fe metal and Fe sulfide are also incorporated into the symplectites at the margins of the symplectite bearing garnets. Except for the symplectites, the intermediate Z material in this sample is texturally very similar to the magnesiowüstite in Sixangkou.

A completely different microstructure occurs at the edge of the melt vein where lath- or needle-shaped grains form a spinifex texture indicative of a more rapidly quenched silicate melt (Fig. 1B). The quench assemblage contains two phases that form elongate grains. One has a low Z contrast similar to the garnet, and the other has an intermediate Z contrast. It is noteworthy that the Fe metal and sulfide in this region of the sample occurs predominantly as large spherical blebs but not as tiny grains dispersed between the other phases. The quenched melt-vein boundary is in contact with a region of maskelynite-like material that is very homogeneous except at the locally altered contact with the melt vein (Fig. 1B).

Using TEM, electron diffraction and energy dispersive microanalysis we were able to identify the predominant phases in the matrix. The most abundant phase is majorite$_{SS}$ ($Mj_{75.2}$ Na-$Mj_{4.1}$ Ca-Mj_3 $Py_{16.2}$ $Uv_{1.5}$), as confirmed by electron diffraction in this study and by microprobe analyses [9]. The main coexisting phase in the matrix is an Fe oxide that produces electron diffraction spacing and symmetry consistent with magnetite. The magnetite is also abundant as inclusions in the majoritie$_{ss}$, where it coexists with a beam sensitive silicate that appears to be a devitrified or altered glass. The morphologies of these inclusions suggest that the oxide and silicate material were trapped as liquids in the growing majorite$_{ss}$ under high P-T conditions. The symplectites observed with BSE imaging are commonly observed with TEM. They consist of predominantly magnetite (Fig. 1C), but are associated with Fe metal and sulfide. The magnetites are generally well ordered and crystalline, but can also be disordered, as indicated by streaking and splitting in diffraction patterns and bycomplex domain contrast in TEM images. High resolution images of the disordered material show that it consists of tiny subgrains of magnetite in a matrix of disordered material. The disordered microstructures suggest alteration, but the magnetites and their origins are still under investigation. The quenched areas contain garnet, but because of difficulties in sample preparation, this material is not yet well characterized.

Microstructures in Melt veins in Tenham; Sharp et al.

Discussion

The matrix assemblage in the melt veins of Tenham is not the magnesiowüstite + majorite$_{SS}$ assemblage that was observed in the Sixangkou L6 chondrite [1] or predicted by the crystal-melt equilibria at high pressures [8]. The presence of magnetite as the second most abundant phase after majorite is surprising because it is not a mineral known from high pressure experiments. The presence of disordered and poorly crystalline magnetite suggests that either magnetite formed as an alteration product of a higher pressure phase such as magnesiowüstite or wüstite, or the magnetite itself was the high pressure phase that has been partially altered. If the magnetite is a primary phase, it represents a new high pressure occurrence. If magnesiowüstite were the primary oxide phase at high pressure, we would have to account for the apparent disappearance of its MgO component. If wüstite were the primary high-pressure phase, it could have disproportionated at low pressures to metallic Fe plus magnetite, which are both present in this sample. The P-T conditions of crystallization cannot be interpreted from the magnetite + majorite$_{ss}$ assemblage as previously attempted [9].

The majorite$_{ss}$-magnetite symplectite generally occurs in association with larger amounts of the interstitial glass and represents the last material to crystallize, whereas the quench zone at the margin of the melt vein probably represents the first material to crystallize. The presence of quenched boundaries indicates that some of the heat associated with the melt was dissipated into the surrounding solid material while the melt vein was crystallizing at high pressure. This implies that the temperature gradients at the melt vein margins, in this case between melt and maskelynite-like material, must have been very high during shock. It also implies that there was enough time for heat transport, probably by conduction, on a length scale of 20 to 40 µm under high pressure and temperature conditions.

References

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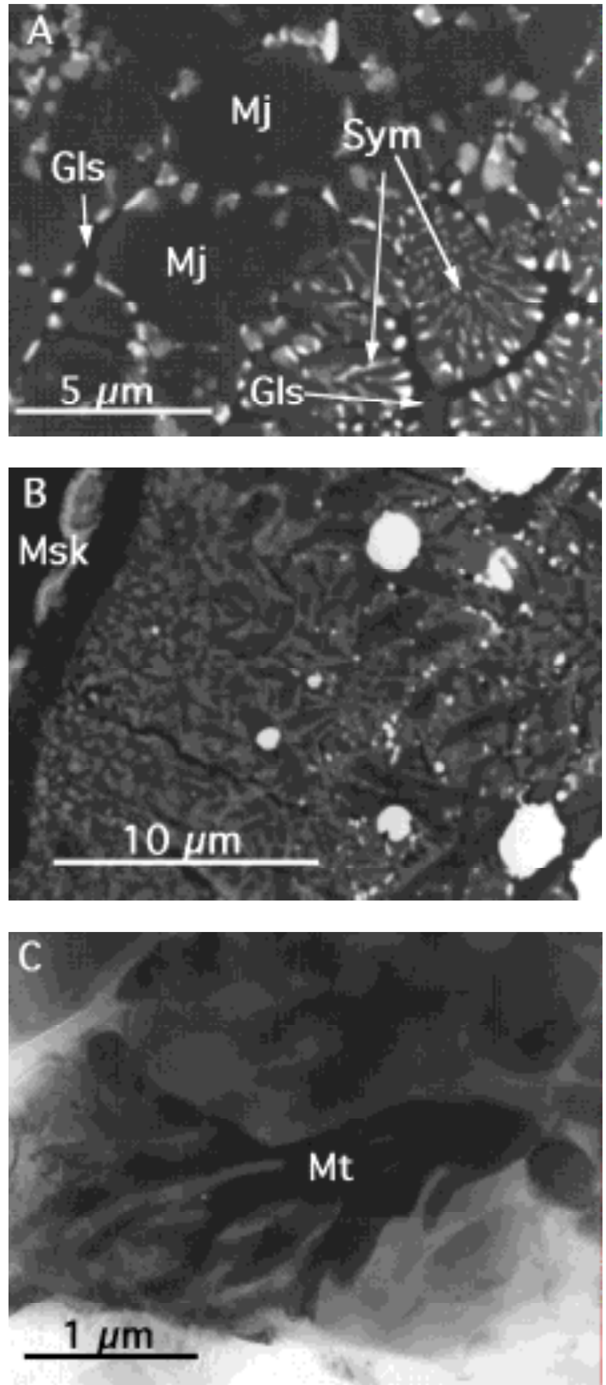

Fig.1 BSE images of (A) majorite$_{ss}$ (Mj), symplectites (Sym) and glass (Gls), and (B) a quench texture in contact with meskelynite-like material (Msk). (C) A TEM image of a magnetite grain in a symplectite.